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APPLICATION OF LINEAR PROGRAMMING TO PLANT LOCATION DECISIONS

By

Robert E. Johnson
Western Electric Company

Since construction of a plant involves considerable sums of money which are invested for many years, optimum location becomes an important factor, and the best available information must be corralled for management decision-making (there being no certain way of avoiding all future risks in a dynamic economy). A recent improvement in technique is constituted in linear programming techniques, of which a simple example is given here.[1]

Let me define what I conceive to be the scientific approach. Basically, this is the same approach the physical scientist uses to solve his problems. It consists of seven steps:

1. Identifying the problem.
2. Analyzing the elements of the problem.
3. Evaluating the available information.
4. Identifying the areas where no data exists.
5. Appraising the relative importance of known and unknown factors.
6. Building (where possible) a mathematical or other type model to simulate the problem.
7. Testing the model.

Certain mathematical tools have been developed recently

[1] A comprehensive text is "Linear Programming and Economic Analysis", by R. Dorfman, P. A. Samuelson, and R. M. Solow. McGraw-Hill, New York, 1958.

which aid in arriving at better decisions. In many areas, the new data processing (or "model testing") tools, such as the high speed computers, combined with mathematics, mean that more precise answers can be obtained. One instance will be discussed in the following pages.

Chart 1 lists some of the factors that management must consider prior to making a final decision in the selection of the site for a new plant. Many of these items, although of great importance, cannot be evaluated directly in dollars and cents. Others require only simple arithmetic for appraisal. However, transportation costs of both incoming raw material and of final shipped product lend themselves to ready evaluation through the technique of linear programming, one of the newer Operations Research tools.

This paper will be concerned primarily with linear programming solutions of location problems where management is thinking of supplementing production from existing plants. (This approach is also useful where a new company is locating its first plant.) The problems may be viewed as being divided into two general types. First, those where management has several alternative sites in mind and would like to find the location which minimizes total transportation costs. Second, those problems where management has no predilections, and may have only a general geographic area in mind. Of course, throughout all of this, management should have a third alternative in mind, and that is the addition of capacity at the existing manufacturing location.

Chart 1

SOME FACTORS INVOLVED IN SELECTION OF A PLANT LOCATION

I. SITE

- a. Availability
- b. Suitability
- c. Zoning Regulations
- d. Utilities (Electric, Gas, Water)

II. TRANSPORTATION

- a. Availability
- b. Costs

III. AREA LABOR SITUATION

- a. Availability and Skills
- b. Salary and Wage Levels
- c. Union Activity

IV. COMMUNITY

- a. Services
- b. Housing
- c. Type of Community

V. RAW MATERIAL SUPPLY

VI. MARKET LOCATIONS

VII. CONSTRUCTION COSTS

VIII. TAXES

IX. LOCATION OF COMPETITOR PLANTS

X. PROXIMITY OF HEADQUARTERS AND OTHER LOCATIONS WITHIN THE SAME COMPANY

Chart 2 reflects the general character of the problem involving fixed alternatives. The lines emanating from the two existing locations show how the final product is being distributed prior to the establishment of the third location. The boxes on the chart show three alternative cities that are in management's mind. It becomes obvious that a new location will upset, to some extent, the original product distribution. That is why there are question marks with regard to the distribution of product from the new sites.

Chart 3 shows all of the transportation cost variables that are interacting in this problem. The lowest water, rail or highway costs have been used, since any form of transportation is suitable for the product. Where no costs are shown for the proposed plants, it was deemed economically unfeasible to service the destination involved from that location. On the extreme right are shown the requirements of each destination in tons of material. On the bottom the capacities of the existing and new plant locations are shown. In solving the problem, combined costs of transportation of the two existing plants, along with each of the new locations, are computed separately by linear programming techniques.

Chart 4 shows the results of these computations. You will note here that the alternative of increasing capacity at the existing locations was considered. Interestingly enough, the combined shipping costs, including proposed Site P-3, showed a substantial decrease from the possibility of increased capacity for the two-location set-up. Also the impact of raw material transportation

SELECTION OF NEW PLANT LOCATION FROM THREE PROPOSED SITES

Chart 2

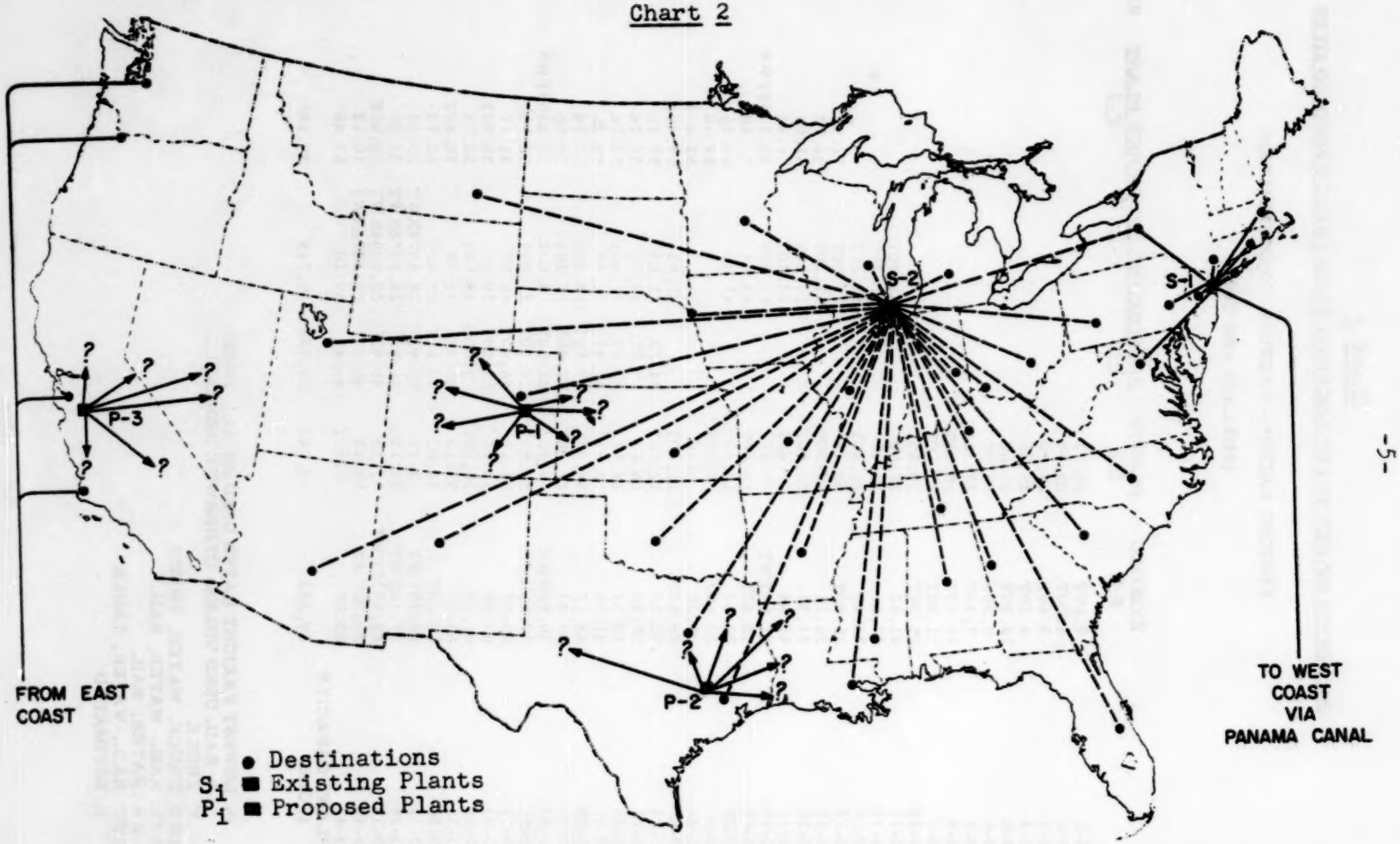


Chart 3

SELECTION OF NEW PLANT LOCATION FROM THREE PROPOSED SITES

FREIGHT RATES* - FACTORY TO DESTINATION

(DOLLARS PER TON)

	EXISTING PLANTS		PROPOSED SITES FOR NEW PLANT			TOTAL REQUIREMENTS
	S-1	S-2	P-1	P-2	P-3	(TONS)
D-1	9.60T	25.53				6,465
D-2	6.00T	25.30				3,885
D-3	3.40T	25.30				2,849
D-4	4.20T	25.30				5,439
D-5	14.80T	21.60				5,827
D-6	5.80T	25.30				7,770
D-7	7.40T	24.38				5,309
D-8	16.40T	18.20T				2,461
D-9	11.20T	23.60T				11,007
D-10	25.00T	10.80T				1,166
D-11	21.62	27.60		41.40T		2,460
D-12	27.37	32.20		37.20T		907
D-13	32.89	22.40T		31.60T		4,791
D-14	26.00T	30.13		32.60T	71.52	4,791
D-15	36.11	39.80T		37.20T	91.77	7,511
D-16	33.35	28.00T		29.60T	61.64	2,979
D-17	40.94	29.40T		22.40T	61.64	1,166
D-18	31.68TWT	33.35		15.40T	32.3534TWR	4,273
D-19	18.80T	13.00T		40.94	72.68	5,957
D-20	22.54	12.80T		41.40	69.46	6,086
D-21	23.60T	8.00T		-	69.46	2,202
D-22	25.30	6.90		-	59.494	3,497
D-23	26.60T	11.40T		41.63	59.494	9,842
D-24	33.58	12.60T	34.73	41.63	55.56	2,202
D-25	35.88	18.63	29.67	38.18	52.74	2,331
D-26	40.94	28.52	27.83	27.40T	52.74	2,590
D-27	31.05	18.63	33.81	32.89	58.26	3,885
D-28	44.62	32.43	22.60T	18.20T	52.74	2,460
D-29	39.33	27.00T	27.40T	17.40T	55.56	1,036
D-30	30.82RWR	39.10	28.60T	5.00E	32.2208TWR	4,403
D-31	39.56RWR	35.88	24.80T	21.80T	52.74	4,273
D-32	60.03	53.13	38.40T	46.92	41.17	907
D-33	63.25	53.13	32.80T	39.56	30.00T	1,036
D-34	51.29	35.80T	5.00E	28.60T	52.74	1,813
D-35	63.25	53.13	46.92	33.35	30.40T	2,590
D-36	59.20T	44.62	19.60T	27.80T	52.74	907
D-37	28.70TWT	53.13	46.92	28.5074RWT	26.22	3,755
D-38	28.30TWT	53.13	46.92	28.1074RWT	23.46	2,331
D-39	28.8920TWT	53.13	46.92	28.6994RWT	5.00E	9,583
D-40	29.30TWT	53.13	46.92	29.1074RWT	10.12	12,691
D-41	23.00	9.60T	41.40	39.10	69.46	907
PLANT CAPACITY (TONS)	69,282	69,283	29,785	29,785	29,785	168,350

* LOWEST FREIGHT RATES USED AT ALL TIMES.
RAIL USED UNLESS OTHERWISE INDICATED.

T TRUCK
TWT TRUCK, WATER, TRUCK
RWR RAIL, WATER, RAIL
WR WATER, RAIL
RWT RAIL, WATER, TRUCK
E ESTIMATED

Chart 4

SELECTION OF NEW PLANT LOCATION FROM THREE PROPOSED SITES

SUMMARY OF TRANSPORTATION COST DIFFERENTIALS- EXISTING LOCATIONS AND NEW PLANT

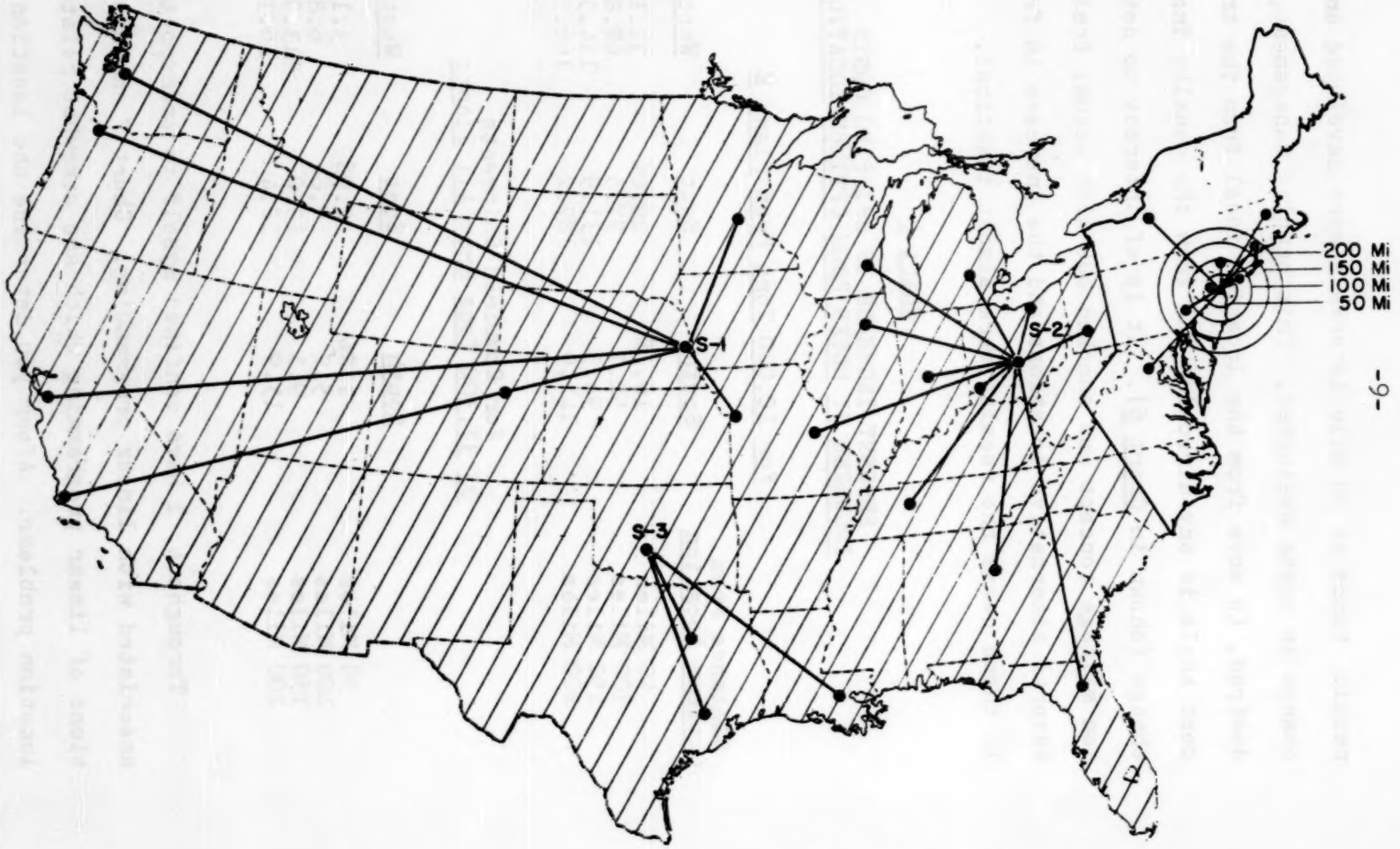
	A TOTAL TRANSPORTATION COST FROM PLANTS	B EXCESS TRANSPORTATION COSTS OF RAW MATERIALS TO PLANT OVER EXISTING PATTERN	C ADJUSTED TRANSPORTATION COSTS (A + B)	EXCESS COST OVER OPTIMUM (P-3 WITH EXISTING PLANTS)
EXISTING PLANTS	$1,646,789.00	0	$1,646,789.00	$ 87,835.76
PROPOSED LOCATIONS				
P-1	1,704,340.96	$151,947.98	1,856,288.94	297,335.70
P-2	1,460,707.99	345,278.70	1,805,986.69	247,033.45
P-3	1,436,062.36	122,890.88	1,558,953.24	0

costs was evaluated and here we discovered a marked increase in costs associated with Site P-2, hence swinging the project in favor of Site P-3. Thus, if management had not had the benefit of this analysis, a penalty of more than $250,000 per year in transportation costs could have been incurred. Actually, we have made similar studies in which variations up to one million dollars per year in transportation were found to exist between alternative choices for new plant sites. In one case, the transportation savings were equal to nearly double the depreciation charges on the proposed plant.

Chart 5 illustrates the general problem where no specific sites are chosen by management and some general area such as the East Coast is suggested. This is far more complicated. Here we see three existing plants and the areas to be served by them under a four-plant set-up (with the fourth plant somewhere on the East Coast). The unshaded section of the chart represents the potential area available for the new plant location. In order to solve this problem, the assumption was made that freight rates vary directly with distance. Such is not necessarily the case. The requirements in tons of product for each destination involved are important factors in determining a weighted central point. In effect, one is seeking the center of gravity in terms of ton-miles. The large encircled dot represents this central point for the problem involved. It was recognized that the central point, although it was the most economical from a transportation point of view, might not be acceptable to management from other aspects of the total plant location problem as listed on Chart 1. As a

Chart 5

SELECTION OF NEW PLANT LOCATION FROM NORTH EASTERN UNITED STATES



result, bands at 50 mile intervals were developed and the relative change in costs evaluated. This enabled management, if it so desired, to move from the location ideal from the transportation cost angle in any direction and know the penalty incurred by the change (shown in Chart 6). It is of interest to note that the ton mileage concept was checked out with actual freight rates for several alternative locations and the increase in freight measured. In these cases the results were almost identical.

Chart 6

PERCENT INCREASE IN SHIPPING COSTS
INCURRED BY MOVES FROM OPTIMUM LOCATION

For 10,000 Tons From Plant E

Distance From Optimum Location	South	East	West	North
50 Miles	18.1%	29.6%	31.1%	42.0%
100 Miles	52.7	77.5	68.8	87.8
150 Miles	94.5	131.9	114.5	141.8
200 Miles	141.9	187.2	166.3	195.0

For Combined Shipments
Of 33,300 Tons From All Plants

	South	East	West	North
50 Miles	1.8%	2.9%	3.1%	4.1%
100 Miles	5.2	7.6	6.8	8.6
150 Miles	9.3	13.0	13.9	13.9
200 Miles	13.9	18.4	16.3	19.2

Throughout, I have confined myself to transportation problems associated with linear programming. Chart 7 shows other applications of linear programming which are somewhat related to plant location problems. After you determine the location of the plant,

it is possible through linear programming techniques to determine the optimum product mix for the plants. One such problem that we worked on represented a choice of establishing facilities to make 100% of Product A, or 100% of Product B, or some mixture of both. Our analysis indicated that transportation savings in the order of $400,000 per year could be realized by a plant making 50% of Product A and 50% of Product B. This would necessitate an added investment of about $3,000,000. But if it is assumed that the cost of money is 5% and that the life of the investment is twenty years, an added cost in the neighborhood of $225,000 a year would be incurred, or a net saving of about $175,000 a year. Other applications of these techniques involve personnel assignment, optimal purchasing policy, machine scheduling, materials handling, and inventory control.

Chart 7

OTHER APPLICATIONS OF LINEAR PROGRAMMING

I. PRODUCT MIX
II. PERSONNEL ASSIGNMENT
III. OPTIMAL PURCHASING POLICY
IV. MACHINE SCHEDULING
V. MATERIALS HANDLING
VI. INVENTORY CONTROL

(See following pages for Technical Appendix)

TECHNICAL APPENDIX
An Explanation of Linear Programming By Means of a Transportation Tableau

Linear programming is a mathematical tool for achieving the minimum costs where supply or demand is restricted and where costs are variable among alternative choices.

There are three methods of reaching linear programming solutions, known as (1) the transportation method, (2) the profit preference method, and (3) the simplex method. Since we are concerned with the solution of problems relating to minimum transportation costs, let us look at a simple problem in the transportation method. It may be stated that the other two methods become mathematically more sophisticated in the order given above.

The chart following this Appendix may seem at first glance to be a complicated numerical and symbolic jungle. It is hoped that the following explanation may clarify both the chart and the methodology.

The bold numbers in the right-hand column and the bottom row represent:

1. In the column, the demand from several destinations.
2. In the bottom row, the capacity available from three sources: S_1, S_2, and S_3.

By definition, or otherwise, those are the restrictions on the problem, i.e., they must remain inviolate.

The lighter numbers, in the center of the cells, represent the cost of obtaining one unit of product for a destination from a particular source. This is again a restriction on the solution, since these are real costs and they cannot be changed.

Now, then, there are almost an infinite number of solutions to the problem if cost is disregarded, but there is one solution where the total cost is a minimum. Let us proceed to find that one solution.

First, we might try to ship to each destination its total demand at the least cost, disregarding the bottom row capacities. The figures within the boxes, □ , accomplish this. But it will be noted that S_1 would ship 90 units, S_2, 0 units, and S_3, 10 units. Thus we would violate one restriction on the problem.

Now, let us start again watching the suppliers' capacities. Suppose we assign destination one's (D_1's) demand to the lowest cost supplier (S_1). This is designated by the figure in the circle, 0. Next, we will move to destination 2. Here the demand is 30 and the lowest cost supplier is S_1, but we have only 5 units available from this source. We assign these 5 units to S_1, and find that S_3 is the next lowest cost supplier, so we assign 25 units here. These are designated by figures in the circles, 0. A similar prodedure is followed for other requirements and the figures are shown in circles, 0. Let us call this our first approximation. It is one solution, but is it the cheapest?

The next step is to build an artificial cost matrix. This artificial cost matrix is shown on the chart as figures within the diamonds, ◊ . In order to achieve this matrix, we must add a new row of figures - shown at the bottom of the table - and a new column of figures, shown in the requirements column. To generate this matrix, we must assume a value - any value - for one column. Let us assume 0.00 for column S_1.

Now, then, the column value plus the new row value equals the value in any cell. Suppose we start with D_1S_1 and use the actual cost .10 as the artificial value. The new column value then is .10, .10 + 0.00 = .10. Moving next to fill values where we have assigned shipments, let us go to D_2S_1. .20(actual cost) - 0.00(column S_1 value) = .20, the row D_2 value in the new column. Row D_2 also receives shipments from S_3. Therefore, let us get an artificial cost for D_2S_3. Again, let us use the actual cost - .30. .30(actual cost) - .20(new row value) gives us 0.10 as the value for column S_3. We can now get a row value for D_3. That is, .25(actual cost) - 0.10 = .15(D_3 row value). This now permits us to establish an S_2 column value.

Having established artificial values for all assigned routes, we proceed to fill in artificial values for all routes.

The next step is to reduce the assigned routes. Here we eliminate all assignments which stand alone in either their row or their column. We have designated such eliminations by an asterisk. Once an assignment has been eliminated, it is considered not to exist. Thus, we are able to eliminate D_3S_3. We must not reduce the assigned shipping pattern below 3, and should have one destination receiving supplies from two sources. As will be seen from the succeeding steps, the pattern of three squares with allocated shipments - and with one destination receiving material from two sources - facilitates the manipulation of the matrix to final solution. Occasionally it is not possible to achieve shipments from two sources to one destination. This is known as degeneracy and can be handled by the use of an epsilon value.

However, this concept goes beyond the confines of this article and is adequately covered in most textbooks in the field. In this case we have stopped with assignments to D_1S_1, D_2S_1, and D_2S_3.

The next step is to compare the artificial cost matrix, ◇ , with the actual cost matrix. The cell where the artificial cost value exceeds the actual cost value by the greatest amount represents the route where the greatest savings can be made. In this case, D_1S_3 exhibits this phenomenon and is designated by the symbol, ↘ .

We therefore desire to maximize the assignment to this cell. It is designated here by a +x. But we must take an equivalent amount away elsewhere in both row D_1 and column S_3, so we place a -x in these cells, where assignments remain. Column S_1 must be balanced so a +x is placed in cell D_2S_1. The maximum amount we can assign to D_1S_3 is 20. Therefore, we readjust the assignments in D_1S_1, D_2S_1, D_1S_3 and D_2S_3, as shown with the symbol ¤. The shipment matrix is still in balance and the new assignment matrix is completed by reinserting the asterisked items now shown in ¤.

The above manipulation is what is known as an iteration. Successive iterations are performed until no artificial value in any cell exceeds the actual cost. At this point, the lowest cost solution has been achieved.

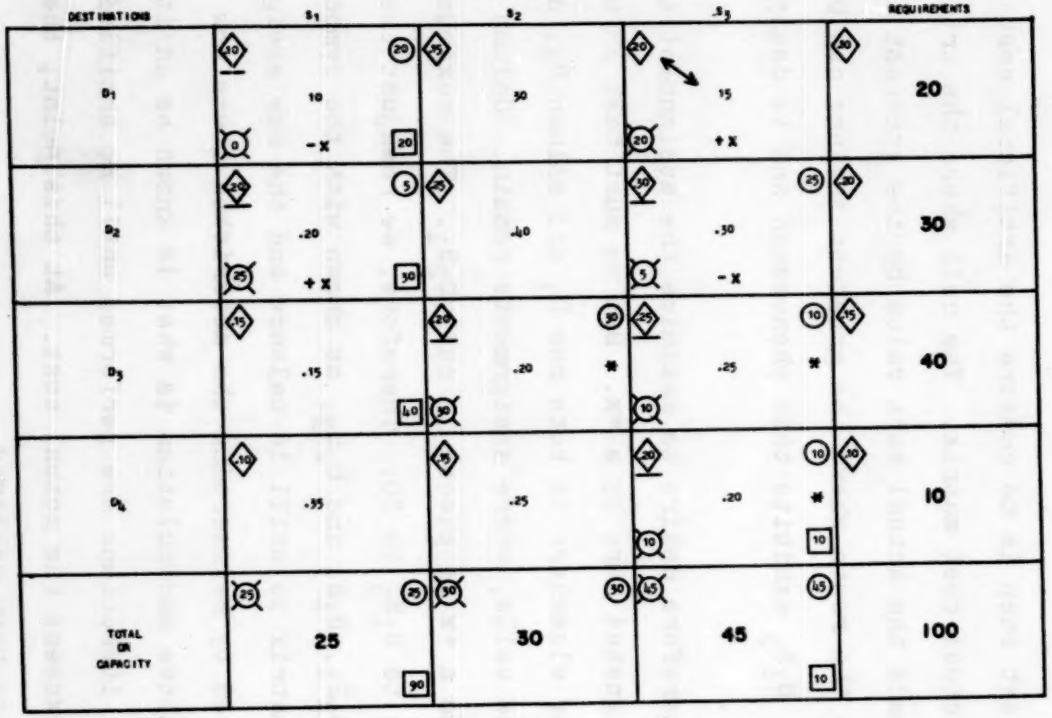
This technique is applicable wherever supply and demand are restricted and alternative costs are variable.

(Chart on p. 16)

LINEAR PROGRAMMING

A SIMPLE TRANSPORTATION PROBLEM

SUPPLIERS



THE USE OF PROBABILITY-MULTIPLIERS IN REPLACEMENT ANALYSIS *

By

Bruce M. Barber
Dartmouth College

THE NEED FOR PROBABILITY ANALYSES

Engineering economy analyses are often made for both the most and least favorable combinations of forecasted future conditions. This procedure has two major weaknesses. First, the two solutions usually indicate that contradictory courses of action should be followed. When this occurs, the engineering-economic study has failed to provide the management of a business with a quantitative aid and mathematical method for evaluating data and arriving at sound decisions. Second, that method of analysis is unrealistic because it emphasizes the extreme possibilities rather than some intermediate situation which is more likely to occur.

Use of a probability analysis eliminates the two aforementioned objections. It permits economically sound management decisions and forecasts to be made if the basic data are reasonably accurate and well established, and if they have been selected carefully. This has been recognized for a long time by insurance companies in setting premiums on policies covering various kinds of individually unpredictable risks, and in the

* This paper was awarded first place at the undergraduate level in the 1958 contest sponsored by the National Center of Education and Research in Equipment Policy at Illinois Institute of Technology, for the best essays in Equipment Policy or Capital Budgeting.

area of business it is feasible to apply probability-multipliers in the analysis of engineering economics problems of all kinds. With this approach, a solution to each problem can be found that has a high likelihood of being substantially correct - mainly because it has been recognized in the mathematical computations that a combination of intermediate conditions has a much greater probability of occurrence than either the "optimum" or the "worst" grouping of the pertinent variables of the problem.

A probability analysis of an engineering economics problem is admittedly more involved and expensive to make than the simpler approaches mentioned in the first paragraph, but the increase in complexity should not be overemphasized. It should be remembered that over 75% of the effort and expense associated with an engineering economy study is usually expended in the collection of the data for analysis. If the computational and analytical labor were doubled for such a case, the total effort expended in collecting and analyzing the data would be increased only 25%. As low grade clerical help can perform the computations once the engineering economy equations are set up, the expense of this additional analysis is even less a factor than one would conclude before thinking about what is entailed in making a probability analysis.

A second objection which can be raised against making a probability analysis is that it is impossible to assign exact probabilities to various possible combinations of intermediate conditions. This is a legitimate comment, but it is nevertheless remarkable how accurate the evaluation of proper action or the

prognosis of future developments is when the significant variables of the problem are selected and individually "weighted" for the analyst by an experienced and competent man.

METHOD OF PROBABILITY-MULTIPLIER ANALYSIS

In any engineering economy problem some data are known, or can be obtained easily, to a high degree of accuracy. Other factors can vary over a wide range and involve a large element of uncertainty. Thus, since the rate structures of public utilities are highly stable, it is easy to estimate gross profits in future years rather accurately when data on such factors as rate of growth of population, lower cost of electric power produced by large generators, etc., are injected into the economic study. Future demand for most products, on the other hand, has no such stability. For such goods it can be effected by the appearance of new competitive products, by the aggressiveness of the sales organization, etc.

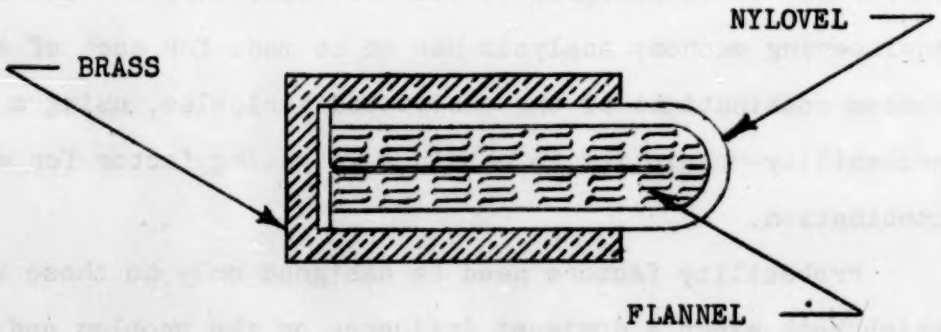
Probability-multiplier analysis involves three steps. First, the different levels in which each varying quantity, such as demand, may fall, have to be determined. Second, a probability factor has to be assigned to each of these levels. Third, an engineering economy analysis has to be made for each of several chosen combinations of the associated variables, using a probability-multiplier to obtain a weighting factor for each combination.

Probability factors need be assigned only to those variables which both exert a dominant influence on the problem and are subject to wide variation. Since power cost is fairly constant

and usually comprises only a small per cent of total cost, it ordinarily does not have probability factors assigned. However, product demand (due to its controlling importance and great fluidity) usually has probability factors assigned to it. Exactly what constitutes a wide range or a dominating variable, and a proper weighting factor for each level, must be left to the judgment of the engineer, after he has discussed the problem with the analyst. The decision on how many demand levels should be used obviously depends upon the accuracy with which a probability may be assigned to each selected level, and on how elaborate an analysis is justified by the importance of the problem.

AN ILLUSTRATIVE PROBLEM

The item to be analyzed consists of a small U-shaped piece of nylovel cloth placed on top of a U-shaped piece of flannel cloth, with the open ends of the two U-shaped cloth pieces held together by a U-shaped brass clip. The diagram below depicts the assembly, known as a "wiper pad" and used as an expendable item for maintaining certain electrical equipment.



Originally the three components of the wiper pad were manufactured as three separate items in a piece part shop. They were then brought together for assembly in another shop. This will hereafter be referred to as the piece part-assembly method or the old process.

A preliminary engineering investigation later indicated that construction of a fully automatic machine to make the wiper pads was feasible and had considerable cost reduction possibilities. Such a machine was accordingly designed. This permitted the establishment of more accurate performance characteristics, and an analysis was next made to determine whether the machine should be built. In this analysis, shown below, the cost figures are per thousand parts.

COSTS UNDER THE "OLD METHOD", FOR ILLUSTRATIVE PROBLEM

A negligible amount of capital plant was required in the manufacture of the component parts under the old method. Only a small portion of the capacity of one punch press was needed to blank out the two cloth parts and make the brass clip, and it is accordingly an unjustified refinement to assign any of the capital recovery cost of a punch press to this job. The cost per thousand parts of the materials was $1.01, $3.85, and $1.36, for the brass, nylovel, and flannel parts. All piece-part work up to three or four times the maximum demand considered possible could be performed on the first shift without any overtime. The labor cost for making the component parts was $2.28 per thousand.

The piece parts next had to be assembled. For this purpose

a special machine originally costing $12,000 - but with no net resale value - was used. Three operators, each paid $1.71 per hour when working on the day shifts of a five-day week, were needed on this machine. The rated output was 743 pads per hour, but this figure depended upon the skill of the operators. While first-shift operators worked at rated capacity, the second-shift crew was only 80% productive. A bonus of 10% was paid to second-shift labor, and time-and-one-half for Saturday work. Using this information, the assembly labor cost per thousand parts, and the output ranges over which these costs prevail may be computed [1] and are shown in Table I.

TABLE I

Mode of Operation	Assembly Labor Cost Per 1,000 Parts	Output Range Over Which Cost Prevails
First Shift, Monday to Friday	$ 6.91	0-1,486,000
Second Shift, Monday to Friday	9.44	1,486,000-2,676,000
First Shift, Saturday	10.35	2,676,000-2,973,000
Second Shift, Saturday	14.12	2,973,000-3,211,000

COSTS UNDER THE "NEW METHOD", FOR ILLUSTRATIVE PROBLEM

The cost of the automatic machine was estimated to be $41,000. It was recognized that it would have no salvage value at any time. Under the new method of manufacture, the cost per thousand parts of the brass, nylovel, and flannel is, respectively, $1.30, $5.04, and 73¢. The reasons why the cost of materials is different from the cost under the original method are (1) that the amount of scrap

[1] See Appendix.

metal is not the same (the cost per pound depending upon the form in which a raw material is ordered), and (2) that coils of cloth of the desired width, rather than sheets of cloth, are purchased. Since only part-time of one operator is needed with the automatic machine, labor cost amounts to only 31¢ per thousand parts. This value prevails at all levels of output.

THE DEMAND STRUCTURE AND OTHER DATA FOR THE ILLUSTRATIVE PROBLEM

Two additional items of information, common to both the old and new methods of manufacture, are needed to complete the economic analysis. The Company in question does not consider it good business to replace, for cost reduction reasons, any old machine or process by a new facility or process, unless the rate-of-return after taxes is at least 20%. A rate-of-return of 40% before taxes will be used in this paper as the closest approximation to the requirement for which tabular values are readily available. The other required information is the estimated future demand for the wiper pads.

It is unknown how large the annual demand will be, or how long it will last. Demand is important because it determines the amount of machine utilization. It is assumed the demand will remain at the level N for n years and then fall to .5N, where it will remain for (10 - n) years. N and n are assumed to be independent of each other. n depends upon how long it will be before pieces of the equipment on which the wiper pads are used as maintenance devices are removed from primary service and are replaced by more modern facilities.

The value of N depends upon how frequently it is necessary to replace the wiper pads, and on the number of pieces of equipment in service which require them. Table II shows the best estimates that conservative manufacturing engineers can make of what the minimum annual demand is likely to be during the next five years, based to a large extent on a study of what it has been in past years. For example, this Table says that a forecast which will be 1,800,000 minimum per year is equally likely to be correct or incorrect.

TABLE II

Minimum N (Millions per year for each of next five years)	0.8	1.2	1.6	2.0	2.4	2.8	3.2
Probability	100	90	60	40	20	10	0

Table III shows an estimated probability that the Table II data will be valid for each of the next five years. It reflects the obvious fact that estimates for the earlier years of the interval have a greater probability of being valid.

TABLE III

n (Years)	1	2	3	4	5
Probability	100	90	60	20	0

THE "PROBABILITY SQUARE" APPLIED TO THE ILLUSTRATIVE PROBLEM

The "probability square" is a simple artifice for presenting data graphically, to aid in visualizing the problem. Imagine the

n-demand structure to be plotted along the horizontal and the N-demand structure to be plotted along the vertical. This is shown by the Table IV box diagram. Each box, or rectangle, represents one of the twenty-four possible independent combinations of n and N. All these possibilities are independent, but they are not equally likely to occur. The uncertainties of their occurrence are written in the boxes. The meaning of the dashed line will be explained later.

TABLE IV

Level of Annual Demand (N)				
3.2	1%	3%	4%	2%
2.8	1%	3%	4%	2%
2.4	2%	6%	8%	4%
2.0	2%	6%	8%	4%
1.6	3%	9%	12%	6%
1.2	1%	3%	4%	2%
0.8	1	2	3	4

Number of Years Demand Lasts (n)

As an explanation of how the probabilities of Table IV are computed, the fourth box from the bottom in the second row from the left will be examined. This corresponds to the situation in which the demand would last for two years and be between 2.0 and 2.4 million units per year. From Table III the probability that the maximum demand will last two years or longer is 90%, and the probability that it will last three years or longer is 60%.

Therefore, the probability that n = 2, or that the demand will fall in the second vertical column from the left, is .90 - .60, or 30%. Now Table II shows that the probability that the demand will be at least 2.0 million units annually is 40%, and that the probability corresponding to a demand in excess of 2.4 million units yearly is 20%. Therefore, the probability that the demand lies in this range is 20%. The probability that the demand will correspond to the situation represented by the box being studied is therefore the product of the two independent probabilities, or 6%. The probabilities of the situations represented by the other boxes are computed in a similar manner. The reader should become familiar with the physical meaning of the Table IV diagram since it will be used to tabulate other data.

THE ANALYSIS OF THE ILLUSTRATIVE PROBLEM

As the first step in this analysis, a determination will be made of by how much, on a present-worth basis, all future expenses associated with the proposed automatic machine exceed or are less than the corresponding expenses of the present method of manufacture under the twenty-four independent combinations of future conditions represented by the probability boxes of Table IV. This will give a quantitative evaluation of by how much one fails to recover the invested capital with the required rate-of-return, or how much extra profit is associated with each combination of conditions. For the purpose of computations it will be assumed that the actual demand associated with any range of demands is at the mid-point of the range. Thus the demand associated with the 2.0

to 2.4 range will be considered to be 2.2 million units per year. For an illustration of the method of computation, the fourth box from the bottom in the second column from the left of Table IV ($n=2$, $2.0 < N < 2.4$) will be used again.

Under the old method of production the equation for the present worth of all future cost is shown below. The zero-time-point of the analysis will be taken as six months from now, as the new machine would then be ready to start on the next year's output. It will be further assumed that its $41,000 acquisition expense will be paid at that date, and that all variable costs for a given year will be considered as having been incurred on the first day of the year. The N terms are quantities of output, and the V terms refer to the total variable costs (including the cost of both materials and labor). The subscript $_1$ refers to work performed on the first shift, while subscript $_2$ refers to second-shift production. The term $(\text{sppwf})_{i-n}$ is the single payment present-worth factor, at an interest rate i, of a sum of money located n years from the present. It is the factor which is used to determine the present value of a single payment at some future time n years from now, as a per cent of that sum.

The term $(\text{uspwf})_{i-n}$ is the uniform series present-worth factor. It is the present value of an uninterrupted series of equal year-end payments beginning one year from the reference of zero-time-point and continuing for n years, expressed as a multiple of one of these equal payments. It could be used to determine the value of a fixed term annuity one year from the date of the first payment.

It should be remembered that N is in thousands since the cost figures V are per thousand units of output.

$$P = (N_1V_1 + (N - N_1)\,V_2)\,(1 + \text{uspwf}_{i-1}) + 1/2\,NV_1\,(\text{uspwf})_{i-8}\,(\text{sppwf})_{i-1}$$

$$= (1486 \times 15.41 + 714 \times 17.94)\,(1.714) + 1100\,(15.41)\,(2.34)\,(.714)$$

$$= \$89,500$$

Under the automatic method the present-worth P^1 is computed from the following equation:

$$P^1 = 41000 + NV(1 + \text{uspwf}_{i-1}) + 1/2\,NV\,(\text{uspwf})_{i-8}\,(\text{sppwf})_{i-1}$$

$$= 41000 + 2200\,(7.38)\,(1.714) + 1100\,(7.38)\,(2.34)\,(.714)$$

$$= \$82,410$$

This means that if this combination of n and N should occur, not only will the investment be recovered with the required rate-of-return of 40% before taxes, but an extra $(P - P^1)$ or \$7,090 will also be earned. The amounts by which each of the twenty-three other possible combinations of n and N will produce an excess or deficit in relation to the "indifference point" where capital would just be recovered with interest are shown in the familiar box arrangement in Table V. The method of computation is the same as illustrated above. Negative terms mean the P^1 exceeds P, and that capital is not recovered with required rate-of-return.

The combinations are not equally probable. If the probability of the occurrence of a given combination is multiplied by the gain or loss which will arise if it occurs, and an algebraic summation of all possible contingencies is made, it can be determined whether or not the proposed investment is justified.

Level of Annual Demand	1	2	3	4
3.2	$ 16,120	$ 27,600	$ 35,580	$ 41,170
2.8	7,470	17,160	23,250	33,450
2.4	- 470	7,090	12,210	17,450
2.0	- 2,040	- 2,790	1,020	4,380
1.6	-16,270	-12,320	- 9,340	- 7,510
1.2	-23,420	-20,530	-18,450	-16,980
0.8				
				Number of Years Demand Lasts

The automatic machine should be built only if the result is positive. When the probabilities in Table IV are multiplied by the dollar sums in Table V, and an algebraic addition of the products is made, the result is $2,570. The meaning of this figure is that if the automatic machine is built, it is most likely that the $41,000 investment will be recovered with the required rate-of-return of 40% and that an additional $2,570 will also be earned. The investment is therefore justified.

NECESSITY FOR WEIGHTING PROBABILITIES

The above illustrative problem shows both the techniques and benefits of probability-multiplier analyses. Consider for a moment what results would have been produced by a "best-worst" analysis. Using the most favorable combination of n and N, the investment would have been predicted as recoverable with interest and an extra $41,170. The worst combination of conditions would

have shown that capital would have failed to be recovered with interest by $23,420. The two analyses would not only have recommended alternative courses of action but would also greatly overstate the losses or gains most likely to occur.

The fact that probabilities are multipliers is just as important as the fact that probabilities are used. When the probability of the occurrence of a gain or loss under a given set of conditions is multiplied by the most likely size of the gain or loss, the probability is said to be weighted.

At present, break-even analyses are used just as widely as best-worst analyses. The best-worst method neglects probabilities; the break-even analysis is criticizable because it fails to weight probabilities. The merit of a probability-multiplier analysis is that it combines the best features of both while avoiding the weakness of each. It uses weighted probabilities. Since the errors involved in the break-even method are not so self-evident as are those of the best-worst analysis, the following section of this report is devoted to a demonstration of the inadequacies of this method.

SUPERIORITY OF A PROBABILITY-MULTIPLIER OVER A BREAK-EVEN ANALYSIS

Break-even analyses attempt to determine whether or not the investor is likely to recover capital with interest. Probability-multiplier analysis attempts to determine whether the investor is likely to make a profit or suffer a loss. There is a fine and important distinction between these concepts. It is necessary to see the distinction and recognize that at one and the same time a

given investor can be both most likely to earn a profit and to fail to recover his capital with interest. This is not the usual situation, but neither is it so atypical that it can be ignored. The explanation of this phenomenon is that the small probability of a large gain more than offsets the larger probability of a small or moderate loss. The illustrative problem in the paper was selected because it displays this characteristic. The reverse case of a small chance of a large loss outweighing the larger chance of a small gain also can exist. It is the weighted rather than the unweighted probabilities which are of importance. Whenever this contradictory case arises, there are always psychological aspects and sometimes tax considerations involved. These, however, are of greater concern to the individual than to the corporate investor.

As an illustration of the computations involved in a break-even analysis, the minimum demand level which would justify the provision of the automatic machine discussed purposely will be determined for the case where n is four years. This demand level is the "indifference point" between the two processes where capital is just recovered with interest but with no extra profit. The method is to set up present-worth equations for both the present and proposed processes, with N as an unknown, and solve the two equations simultaneously for N. The symbols in these equations have the same significance as formerly. Thus for the proposed method:

$$P = NV(1) + NV(uspwf)_{i-3} + 1/2\ NV(uspwf)_{i-6}\ (sppwf)_{i-3} + 41000$$

$= N\ (7.38)\ (1 + 1.59) + 1/2\ N\ (2.17)\ (.365) + 41000$

$= 22.04\ N + 41000$

The corresponding equation for the present method of production is shown below. It is valid only for N less than 1486 since cost under the old method depends on the extent to which the work is performed on the second shift.

$$P = NV(1) + NV\ (uspwf)_{i-3} + 1/2\ NV\ (uspwf)_{i-6}\ (sppwf)_{i-3}$$
$$= N(15.41)\ (1 + 1.59) + 1/2\ N\ (15.41)\ (2.17)\ (.365)$$
$$= 46.04\ N$$

Equating the two present worths and solving for N

$$41000 + 22.04N = 46.04N,$$

whence $N = 1710$

However, this answer is not correct, because the second equation was valid only for N less than 1486. Since the value of N has now been proved to be in the range $1486 < N < 2676$, another equation for the present worth of all future costs must be set up. Subscripts have the same meaning as formerly.

$$P = N_1V_1(1 + uspwf_{i-3}) + (N - N_1)\ V_2\ (1 + uspwf_{i-3}) + 1/2\ NV_1(uspwf) - 6\ (sppwf) - 3$$
$$= 1486\ (15.41)\ (1 + 1.59) + (N - 1486)\ (17.94)\ (2.59) + 1/2\ N\ (15.41)\ (2.17)\ (.365)$$
$$= 52.9N - 9700$$

Equating this value for the present worth of all future costs to the corresponding figure found above for the new automatic

equipment and solving for N

$$41000 + 22.04N = 52.9N - 9700$$

$$N = 1645$$

The production level N for the other possible values on n (namely 1, 2, or 3), which makes the choice between the two methods immaterial, can be computed in the same way. The results of these calculations are tabulated in Table VI.

TABLE VI

Years of Maximum Level Production (n)	Break-even Level of Production (N)
1	2210
2	1990
3	1765
4	1645

The meaning of the dashed line of Table IV can now be more easily understood. It is the break-even level of production line. It is obvious that the probability that one is below the dashed line is the probability that the investment will not be recovered with interest, while the probability that one is above the line is the probability that one will not only recover the investment with the required rate-of-return, but will also make something extra. Dividing the probabilities of these boxes which the dashed line intersects, on the basis of the areas above and below the line, it is seen that the chances are only forty-eight in one

hundred that one will be above the line. In other words, if one makes an investment in the new automatic equipment, it is more likely that the capital will not be recovered with interest than it is that it will be so recovered. However, as was shown above, the investment is justified because the smaller chance of a large gain more than counterbalances the larger probability of a small loss.

CONCLUSION

This paper has endeavored to demonstrate by argument and illustration the inherent superiority of probability-multiplier analysis, over either the break-even or the best-worst choice method. The increase in complexity, small in itself, becomes insignificant when contrasted to the more accurate and useful results it produces. The more accurate the engineering-economic analysis, the more useful will this tool become in aiding managers to make decisions.

APPENDIX

The formula $\frac{N(R)(M)}{O(C)}$ is used to compute the cost per thousand parts. N is the number of operators, R is the base rate of pay, M is the rate-multiplication-factor for second-shift or Saturday work, O is the rated machine output, and C = .8, the productive correction factor for second-shift work.

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Review

CARGO CONTAINERIZATION IN THE WEST COAST-HAWAIIAN TRADE *

The question posed is a complex one, and in order to clarify it the author describes the present shipping system operated by Matson. Fifteen cargo ships operate to Hawaii on a schedule of two sailings a week out of San Francisco, one sailing a week out of Los Angeles, and somewhat less frequent sailings out of Pacific Northwest ports - a total of about two hundred round trip voyages per year. Operating cost figures have shown that almost half of the total transportation costs from shippers' to consignees' doors is directly associated with cargo handling to and from the ship, and that this cost is steadily rising.

Investigation disclosed also that about half of the total cargo is potentially containerizable, and hence the possibility of consolidating such cargo in large units for quicker and cheaper handling appeared attractive. However, many problems required attention before a decision could be made as to whether or not to go ahead with a large-scale containerization program. For one thing, the volume of containerizable cargo was out of balance by a ratio of about three to one in favor of west-bound over

* Foster L. Weldon: Operation Research, Volume 6, Number 5, pp. 649-670, September-October 1958. This paper is a summary account of a detailed systems study carried out for the top management of the Matson Navigation Company as a part of their long-range planning program. The basic question to which the study addresses itself is whether or not the company should develop and operate a cargo-container shipping service as an integral part of its West Coast-Hawaiian shipping operations.

east-bound shipments. This means that for a large scale operation the costs of returning empty containers to the mainland must be taken into account. Another consideration was the variation in size of the individual shipments. Large containers or trailer vans are of course most efficient for large shipments, but their use would mean many more less-van-lot (LVL) shipments to deal with than if the containers were smaller. Other factors include the amount of waste space when stowing cargo in containers of different sizes, weight limits on individual units (on the basis of highway trailer weight restrictions), and cost of conversion of cargo ships for carrying various proportions of cargo.

After preliminary investigations to clarify the problems, operating cost studies were undertaken to solve them. The method used was to compare the costs incurred during a whole year of actual operation with the costs as they would have been if various containers systems had been in effect. The vans chosen for analysis were 8 feet wide by 8½ feet high and of lengths 12, 17, 24, 35 and 40 feet. They were to be lifted on and off by means of cranes. A total of nine different fleets of ships were considered, each containing the present total of fifteen ships but having different numbers of them converted to carry vans on deck and/or in holds. Knowing fleet compositions, ports served, and loading and discharging rates to be maintained, it was then possible to determine the number of vans, trailer chassis, tractors, and cranes needed in each case.

Direct operating costs are defined as those costs that are incurred as a result of the direct handling operations on each

ton of cargo flowing through the system from shipper to consignee. The figures were obtained by breaking down the complete operation into fourteen components for each of five general types of cargo on four general routes. Results are presented graphically in a plot of percentage of direct operating costs vs. total van capacity in the fleet (in measurement tons), with separate curves for each of five different van sizes. A steady reduction in cost is shown as proportion of containerization increases.

Fixed operating costs are defined as those that are incurred as a result of maintaining and operating a fixed fleet of ships on a fixed schedule. Figures included overhead, depreciation, maintenance, and operation of ships, terminals, containers, chassis, tractors, trucks and cranes. The plot of results shows a steady increase in direct costs with increasing containerization.

Total operating costs, the sum of direct and fixed costs, are finally presented. The net effect is a downward trend of cost with increasing containerization. The medium-sized van, 24 feet in length, was found to have the minimum total annual operating cost for this particular service, no matter how many vans were assumed. Furthermore, for any particular added capital investment, this size resulted in the largest reduction in annual operating cost over conventional break-bulk operation.

The author points out that the real problem of management is how far to go with a container system in terms of additional capital investment (i.e., number of vans in the system). To provide a basis for decision, a final graph is presented showing operating cost reduction as a percentage return on additional

capital invested, plotted against additional investment. This shows a definite peak of return at an additional investment of about 40% of the original capital. The 24 foot van still shows up best. One might conclude that a relatively modest investment in vans would be desirable as a starting point, with additional capacity added as judgment and experience dictate.

This paper is notable for its thorough and practical treatment of a complex problem. As the author states, "It does not tell top management what their decision should be, but it does give them the information they need to formulate their decisions." Although electronic computers were used to handle the large volume of calculations required, the emphasis of the paper is on the all important matter of thoroughly analyzing the problem and carefully selecting the basic variables.

On the basis of this comprehensive study, the author reports, the Matson management has decided to pursue plans for a large-scale scheduled van-cargo service.

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Review

ACCOUNTING AND THE DETERMINATION OF THE RATE OF WEAR AND TEAR of the BASIC MEANS OF PRODUCTION *

This article deals with the two major problems in depreciation: how to determine actual wear and tear and, thus, life of equipment; and how to treat depreciation and its associated expenses in the accounting records. With regard to the first, the author recognizes that a certain amount of arbitrary action is probably inevitable. Industry in the USSR is evidently bound by its own equivalent of "Bulletin F", which sets "amortization norms" or depreciation allowances for each class of machinery; and it is found that these often do not correspond to actual operating experience. The machine may be scrapped either before its allocated life span, or survive fully depreciated. This fact is, of course, quite familiar, and the author has no suggestions to offer beyond pointing out the problem. He also questions, for technical reasons, the straight line method which is now generally used. Yet it is almost impossible to justify, on functional grounds, any regulated alternative method, such as declining balance or sum-of-the-years-digits.

The real interest in this article lies in its description of

* A. Dodonov: Problems of Economics, Volume 1, Number 3, July 1958 - English Translation of the USSR Journal Voprosy Ekonomiki (The Journal of the USSR Academy of Sciences, Institute of Economics). Authorized Translator and Publisher: International Arts and Sciences Press, 33 West 42nd Street, New York 36, N.Y. $50.00 a year. $4.50 a copy. $20.00 a year to persons associated with institutions already subscribing.

Russian methods of depreciation accounting. The most significant feature here is the sharp differentiation between "running repairs" and "capital repairs". When a machine is bought, an estimate is made of the capital repairs. The latter include any work requiring new parts or the refinishing of existing ones. The amounts budgeted for this may be considerable; the author's numerical example gives 50% of first cost of the machine (a lathe) as an estimate of total capital repairs in a ten year period. The total of first cost and budgeted capital repairs is used as the basis for determining annual depreciation charges, as aforesaid, on a straight line basis.

These funds are deposited with a special bank and the appropriate ministry has the authority to distribute unexpended capital repair funds among other enterprises within its jurisdiction. However, the costs of any capital repairs actually carried out by the plant in question are deducted from the depreciation funds deposited. It is easy to see that if the capital repair funds are regularly exceeded, it is possible to keep payments to the central bank at a minimum and correspondingly reduce the likelihood of having them spent on somebody else's machinery. Conversely, with capital funds underexpended, the machine soon acquires a negative remaining value and the large funds on deposit at the bank may pass to other purposes.

The author questions the whole concept of capital repairs because of this distortion of "remaining value". According to him, this is defined as

$$V_n = C - \left[\frac{n}{N}(C + R) - \sum_{o}^{n} c_a\right]$$

where V_n is the remaining value after n years, N the life of the equipment, C the first cost, R the total capital repairs budgeted for N years,and the last term the total actually spent on capital repairs up to time n. Clearly, by actually spending more than what is budgeted, V_n can be indefinitely prevented from reaching zero. The older the equipment, i.e., the more often and more expensively it has been repaired, the more valuable it thus appears.

It is not surprising, therefore, that overexpenditure for repairs seems to be the rule in the industries which are heavily mechanized in the USSR. The coal industry exceeded its capital repair budget by 111%, electric power by 34.5%, timber, paper and woodworking industries by 17%, and the oil industry by 14%. While, in the coal industry, part of this may be due to developmental difficulties in the very elaborate coal mining machinery now in use in the USSR, the excess is nevertheless considerable. Moreover, the definition of capital repairs itself appears to have been stretched somewhat. The costs of spare parts are stated to be no more than 25%-30% of the repair jobs and 5%-7% of the first cost in many cases. A large automotive repair depot is cited as an example.

Having effectively pointed out the absurdities of this system and having, in fact, cited a recondite passage in the Marx-Engels correspondence, in support of his views, the author nevertheless disclaims all desire for changing procedures. He is, however, in favor of "a certain precision" in the determination of the appropriate bookkeeping entries.

Two comments appear to be in order. First, this system has in the past encouraged extensive repairs, perhaps excessive ones by some standards. On the other hand, such practices have social value in cases where new machinery is expensive in terms of social inputs, if not in terms of price in the capitalist sense. With the Soviet economy now turning out capital goods in large quantities (for example, lathes produced on an assembly line), such practices may no longer have as much justification.

The second comment relates to the reluctance of managements in all industrial societies, regardless of political organization, to lose control over funds first generated under their purview. In the United States and Great Britain, for example, this has led to the practice of charging off as much as possible in the form of regular maintenance expenses, which are eventually closed to profit and loss for the year rather than to capital accounts. This is done primarily for tax reasons, since a deductible expense reflects a considerable tax credit. This is quite apart from the use of methods of writing off equipment which are more rapid than the straight line method. This may be rationalized as the desire to hang on to more money sooner and the hope of tax cuts in later years.

In the Soviet Union, competition between enterprises has so far taken place at the sources of capital and raw materials, rather than in the ultimate market as in the West. In his recent book "Factory and Manager in the USSR" [1], J. Berliner has described

[1] Harvard University Press, Cambridge, Mass., 1957.

the elaborate devices and maneuvers often adopted by managers of individual plants for securing these inputs. The present article clearly shows one more version of the long struggle for the preservation of internal funds, in the face, no doubt, of carefully devised fiscal legislation. The payments to the central bank may be regarded as equivalents of corporate taxation, and so they tend to be minimized.

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"Probabilistic Considerations in Equipment Replacement Studies"

A Note

We are indebted to one of our readers for pointing out that in publishing Salah A. Elmaghraby's paper, "Probabilistic Considerations in Equipment Replacement Studies", in our Summer 1958 issue, we neglected to mention that Mr. Elmaghraby's research was done at Cornell University.

Review

THE SOURCES OF INVENTION *

This book has two very different parts. The first and main one, to page 260, evidently chiefly by Professor Jewkes, economist at Oxford University, is an argument aimed at belittling and casting doubt upon the inventiveness of the corporate laboratories; it fails. The second part, of 148 pages - more by Sawers, another English economist, and chiefly by Stillerman, a Chicago attorney - is "Summaries of Case Histories" of fifty important inventions from about the last sixty years, alphabetically arranged and including such inventions as the Ball-point pen, Freon, Cyclotron, Helicopter, Long-playing record, Synthetic detergents, and the Zipper. Eleven others are listed on page 72, and there is a chapter on nineteenth century invention, lists of inventors, etc. The histories of inventions are competent, highly factual, well documented, attentive to German, British and other foreign inventors, and can well correct our propagandized impressions that America has done it all; they are the valuable part of the book, and can serve many purposes of divers students of invention and history.

The motive for combining these two diverse parts in the book lies in the intent to establish the case histories as proof for

* John Jewkes, David Sawers and Richard Stillerman: Macmillan Company, London, 1958. 31s.6d. St. Martin's Press, Inc., New York, 1958. $6.75. 428 pp.

Editor's Note: It was felt that a review of this book would be of definite interest because of the highly important role played by invention and innovation in bringing about obsolescence.

the generalization of the first part, above all its contention that the laboratories have been overrated. This fails for a number of reasons:

(1) We have no evidence nor even assertion that the instant inventions were not selected to prove that thesis. Inventions are things so vastly diverse, each one by definition different from anything ever seen on earth before, that instances could be found to prove any thesis. As a rule only statistics, which transcend choice, transcend personal experience, memory and interest, to take in the whole of the truth, can prove anything in social science. But statistics are scarce in this book; only seven brief tables are supplied, and the great majority of Jewkes' pages supply no quantification but the page number and an occasional date. He says that statistics are almost impossible to use on invention; but writers not cited by him, such as Ogburn, Rossman, Carr and Steelman, have been able to apply statistics with good effect, even if others have blundered.

(2) The case histories and the whole book exclude for the most part vast classes of modern inventions, viz., the military ones (which like aviation, rockets, navigation, metallurgy, constantly interchange with civil technology), and also agricultural, medical and other governmental inventions. Statistics which could easily have been found in the Statistical Abstract, but are missing here, show that governmental inventing (R & D) has risen to equal that privately financed. Further omitted are the sciences Physics and Chemistry, which are often cultivated in close connection with and for the sake of invention, for which

they provide a base that may be almost sufficient: Professor Urey says that the pure science of one year is commonly the applied science of ten years later. But Jewkes says (page 16) "It is not known whether there is any necessary connection between the growth of scientific knowledge and invention or, if there is a connection, what are its laws." Lastly omitted are trivial inventions when not part of any instanced big one; though trivial individually they are so vastly numerous as to be important in the total picture.

(3) Though the aim of the work is to explain contemporary invention, the main instances cited go back as much as sixty years, and others one hundred and ninety years. How could one prove anything about modern invention and the laboratory system, by reasoning about inventions made without laboratories, in bygone milieux very different from today's, back when great laboratories were non-existent and undreamed of? There were scarcely any before 1920, and their great efflorescence has been in the last decade or two. Our fathers and grandfathers made some inventions without them. So what? Does that prove that our laboratories are inefficient, or overvalued, or less necessary today, or that an heroic free-lance inventor is worth more than a kept stable of hired engineers and chemists? Yet such is the tenor of the arguing.

Let us apply a little statistics to this list, such as it is, striving to date the inventions according to Jewkes' conception of invention. Sixty per cent of them will be dated 1920-39; of those earlier than this period, eight out of ten are ascribed to free-lance or enterpriser inventors, but of those dated 1940 and

later, only five-ninths, four-ninths being laboratory inventors. The trend is evident and understandable.

A basic reason why Jewkes fails to establish his thesis, or to impress us by his constant belittling of the laboratories, is that he has chosen a wrong definition of invention. Please do not call the reviewer a pettifogger for belaboring the definition of one word - it is vital in this case, because Jewkes has chosen a definition of invention such that no economic thesis about it could be proved; it is not an economic definition. He says (page 19), "This essay is almost wholly concerned with invention and not with development"; and he labors to distinguish development from invention, seeming to define invention as the first clear grasping and presentation of a general plan for a new chemical or physical procedure for practical and non-military ends, which kernel in time, after vast development labors, may become thought of as the core of something spoken of as one important invention, called by one name, e.g., Helicopter. Whether the Rotodyne and convertiplane now taking off vertically and flying like airplanes, are helicopters or another invention, and whether their gas turbine, jet and other engines, the fuels, metals, metallurgy, etc., which all aircraft embody, are parts of the Helicopter or are other inventions, are questions he never bothers about, though they would confuse a statistician trying to prove something. Indeed there are no statistics to be found on inventions so defined, unless on the shaky assumption that whatever some writer, or consensus of writers, calls an invention <u>is</u> one and not two or three inventions, or one-seventh of one. Jewkes

is trying to use a linguistic-social, or a physical science definition of invention. An economic definition would have to include Development, and would be something like: Invention is learning to do new practical things, or practical things in better ways. Or rather, we should adjust our definition to what statistical data we can find, and say that invention is reflected in the expenditures for Research and Development, or in the routine-breaking work of engineers, physicists and chemists. With such a definition one could prove something. For instance the reviewer, in a study later to be published, has contrived yearly indices of American inventive effort; it has gone up prodigiously since 1880, whereas patents to Americans have risen only two and a half-fold.

Jewkes' definition of invention leads him to reasoning like this: There is a Chinese proverb that a journey of 10,000 li begins with a single step. A transoceanic voyage begins with the first 100 feet. Such a distance is best covered in a rowboat - a liner is much too clumsy and expensive for traveling 100 feet. So if we wish to help transocean voyaging, we should study and encourage rowboats. Or, shifting back to the content of this book, if we wish to encourage invention we should study and encourage, not the big laboratories, but "the inventor" (by Jewkes' definition), who is usually, he claims, a free-lancer, a man outside the corporate laboratories, a professor or a small manufacturer perhaps, who first thought out the master idea, which in time was wrought into something called a great invention, after governmental or corporate developers had poured into it ten thousand man-hours

and dollars for every one "the inventor" had put into it.

To define invention thus makes no economic sense. In economic reasoning, every dollar's worth of input that is needed for the final product may be as important as every other dollar's worth of input. A great idea, the kernel (as one thinks of it) of a nascent great invention, is <u>not</u> a unique and precious thing, like the silkworm's eggs once secretly brought from China - it is commonly duplicated and cheap. Who "invented" the helicopter? Was it Sikorsky, or Focke, or some other of the dozens who were inventing and flying them for a century past; or was it Leonardo da Vinci, or the unknown Chinese who invented and flew a coaxial helicopter, called a flying top, sometime before 1600? There were about thirty-five steamboats built before Fulton's "Clermont". Patent office history is full of anticipated and duplicate inventing. From statistical facts the reviewer has been able to estimate that something like 95% of the inventions which get as far as a patent attorney's office fail to get a patent, or would lose it if tested by an infringement suit, simply for the reason of anticipation, or for "want of invention", which means about the same thing, viz., that prior workers had so well prepared the way that the claimant's contribution would be too easily duplicated by other seekers, to warrant a patent. But our 95 percentage of duplication must be further heightened by the indubitable fact which many potential, would-be inventors discover before they get to an attorney's office - that their idea has been anticipated. Duplication is the normal thing with invention in Jewkes' sense, whence it follows that new ideas are <u>not</u> unique,

indispensable and invaluable.

Now of course this does not mean that an individual inventor, whether pioneer or developer, is redundant, valueless, and needs no support by patents or otherwise. The fact that some other doctor could save my life, as well as the one I go to, does not mean that doctors are redundant, useless, and should be left without means for support. Jewkes seems confused on this point in pages 17-18, in protesting that individuals are important, that their getting new ideas early is also important; and that invention cannot be reduced to a mere social process. No one says it can; but to talk social science at all, we have to reduce men, for the nonce, from individuals to types, replaceable role-players, statistic-s. Nor does anyone deny that inventors are rare, special, precious types, who need study, encouragements and rewards, whether in or out of a laboratory. Nor does anyone deny that producing their inventions earlier rather than later is a decided service, for which considerable duplicate inventing is a natural and perhaps not too high penalty to pay for early and sure production - unless we can think of some better way to organize invention, as governments and monopolies always do.

Since he uses so little statistics, Jewkes relies on two other forms of reasoning - reference to historical cases, which we have found so variously mishandled and incapable of proof, and the deductive reasoning of classical Economics as to what must follow from the well-established principles of that science. Unfortunately such reasoning can prove things only when the case is simple, or when quantification is supplied. Take for instance

the questions that puzzle him for many pages, whether the great or smaller firms, or monopoly, oligopoly or competition, are best suited to encourage invention, and development. There are some deductive reasons why the large companies should do better than the many small, especially the reason that they can put their discoveries to more and quicker use, without the trouble and uncertainties of patents. But on the other hand, there are economic principles, and also historical instances (of path-breaking invention) pointing to more success from the many small than from the few large. We find weights in both pans of the balance, and if we have no statistics, no way to quantify things, how can we say which way the balance will tip? Considerations do not weigh themselves, they must be weighed by economists who will take the trouble, and who in this case need also much technologic and business information. Jewkes is commendably modest in rarely claiming to have established any proposition. But the reader is afforded little more than a good display of mental gymnastics in the use of principles of Economics, and is left like Omar Khayyam, who

> " . . . heard great argument
> About it and about, but evermore
> Came out by that same door where in I went."

We are left after all simply with the personal opinion of these three authors, that the laboratories have been overrated. Since many experts have thought otherwise, like Conant, Galbraith, Maclaurin, Walton Hamilton and Till, Kaempffert, and Bernel, cited on pages 29-30, we are forced to ask if the three present writers have any higher competence than those. We find nothing

special, except in technic history for the junior authors. And since we are forced to assess the opinion by the man, for lack of scientific evidence for the opinion, we must look also for prejudices. We think we see, all through Jewkes' chapters, biases away from war and from government, and in favor of old-style, competitive small scale private enterprise, and also in favor of English rather than American ways.

Other writers on the social controls of invention are not used or cited extensively, and on its psychology scarcely at all. Some of the very best works are never cited, even when argued against.

Little is said about patents, and that little is highly critical. "It is almost impossible to conceive of any existing social institution so faulty in so many ways."(p.253) Yet no proposals on patents are made, except the addition of public awards for inventors, and retention of patents "so long as nothing better can be suggested for the purpose". If the authors would take off their blinders for a minute, they might perceive that there are in use abundant substitutes for the patent system, in invention by government (as abundant as the commercial) and by trade associations, foundations and universities; also in tax benefits, suggestion systems, trade-marks, sale of know-how, secrecy, and monopoly. Patent statistics are also here condemned; but they <u>can</u> be used intelligently.

In fine, we find scant value in Jewkes' work, but much in the well-documented and detailed case histories of inventions, by Stillerman, who covers much of the non-military inventing of the

last two generations. May we add one small correction here - that Magnetic recording, an invention they would date 1898, was deliberately wrecked in America by C. D. Rood, in 1908-1930, apparently lest it record telephone conversations and compete with the dictaphone; and that it was the German, not the American, Navy which first used this telegraphone to send and receive radio signals at high speed, with Rood's assistance, in order to sink Allied ships in the first World War - while our Navy heard only incomprehensible buzzing.

A useful book, for such historical purposes only. The principal author writes well, like a true English scholar, and the book is well indexed and printed. The research was paid for by the University of Chicago.

S. Colum Gilfillan

Chicago, Illinois

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Review

DEPRECIATION *
History and Concepts in the Bell System

A half century of controversy over the treatment of depreciation in railroad and public utility regulation culminated in a decade of storm and fury, ending in the late '30s. The appearance of a new book on depreciation two decades later is indeed newsworthy. It is a somewhat nostalgic, as well as a gratifying, picture of a champion reviewing the old battles, overlooking some of the intermediate victories and defeats, and ungrudgingly accepting the new order of things.

The preface to the book discloses primary authorship by J. R. Marden, General Inventory and Cost Engineer, Pacific Telephone and Telegraph Company. It is a direct statement of purpose, and of the scope of work. The purpose is to provide the Bell System personnel with a historical review and educational material depicting the part played by the Bell System in the evolution of the depreciation concepts, and to mark the paths traditionally followed by the Bell System. Even the classifications of personnel to whom the text would be useful are specifically listed. The scope of the book is restricted to the review of the past and present policies, practices and experiences of the Bell System.

To the general reader, the introduction to the book, comprising some twenty pages, is of particular interest. It is a

* American Telephone and Telegraph Company, Operation and Engineering Department. Foreword by C. N. Ostergren, Depreciation and Basic Studies Engineer: Published by the Western Electric Co., 1957. Distributed by Graybar Electric Co., 21-15 Bridge Plaze N., Long Island City, N.Y. 154 pp. $4.25. May be ordered through any local Graybar Electric Company office.

concise, clear summary of issues reflecting the economic aspects of property of limited life expectancy. It places proper emphasis on "the Number One depreciation problem in the utility field today" (page 20) - whether depreciation accounting should give recognition to the changing value of the dollar, a depreciation problem of growing importance to all industry.

The major part of the text (eight of ten chapters) is devoted to the period ending in 1937, when the current depreciation accounting practices for public utilities became established. Only the last two chapters, presenting approximately one seventh of the text material, relate to the development and the problems of the last twenty years.

The Bell System took a definite position regarding the establishment of depreciation accounting at an early stage. Notwithstanding the violent opposition to depreciation accounting by the powerful railroad interests, notwithstanding early court decisions in which depreciation was disallowed as a charge to expense because it did not represent "expenditures as actually made", the management of the infant American Bell Telephone Company in 1884 issued a recommendation to its licensee companies in which depreciation was clearly recognized as a cost of operation. A review of subsequent accounting circulars brings the reader to the Uniform System of Accounts for Telephone Companies, issued by the Interstate Commerce Commission in 1913.

During the decades 1913-1933 named by the author "the period of controversy", the conflict between depreciation accounting policies and practices of the telephone companies and the

retirement accounting of railroad and of gas and electric utilities is brought sharply into view. Reference is made to the further conflict between the principle of original cost versus replacement cost of depreciation accounting. The story is well and interestingly told.

An entire chapter (Chapter 7) is devoted to the presentation of the viewpoint of the Bell System in the hearings before the Interstate Commerce Commission in 1928. These hearing resulted in the adoption by the commission of its order on Depreciation Charges of Telephone Companies effective January 1, 1933. The chapter includes an excellent description of the group method of depreciation accounting as contrasted with the unit method.

It is in a description of the 1913-1933 period, however, that one finds a peculiar omission. These were the years when some of the major subsidiaries of the Bell System claimed in their rate cases that the standards used in calculating annual depreciation expense, and the depreciation reserve accrued therefrom, were not appropriate for determining the amount of depreciation deduction for rate base purposes. The extensive commission and court proceedings, in such cases as those of the New York Telephone Company and the Illinois Bell Telephone Company, had a considerable influence in the development of depreciation concepts and regulatory practices. Yet these cases are overlooked with a rather casual remark (pertaining to 1913-1933): "However, little if anything developed during this period that had much effect upon the fundamental depreciation accounting practices of the Bell System" (page 70).

Failure to record these landmarks and their implications leaves a blind spot for a reader who limits his review of the background of the depreciation concepts to this one book. A summary of some of the leading commission and court cases, in which deductibility of depreciation reserve was an issue, would make it easier for a reader to visualize the prospect of a basic change in the treatment of depreciation in the case of a utility industry which has passed the period of growth and entered maturity, relatively speaking.

The foreword to the book warns the reader that it is strongly colored by the Bell System's viewpoint. With a constant consideration of this limitation, the book is a most useful one. It is timely in that it brings the treatment of depreciation problems to the present day, including the original cost accounting and the new provisions for accrual of annual depreciation for income tax purposes.

The text is delightfully illustrated by juxtaposition of photographs of the old and the new in the Bell System.

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Review

CHEMICAL PROCESS ECONOMICS *

Although written primarily with application to the chemical process industries, this book is essentially a general treatment of engineering economy and should be of interest to all engineers concerned with project evaluations. The principal emphasis is on the determination of the profitability of new installations, or modifications of existing ones. Relatively little consideration is given to the detailed methods for estimating project costs or to general economics of the chemical industry.

The first part of the book deals with rather simple indices for judging profitability, without considering the time value of money. This is followed by a more complex treatment, comparing various methods for allowing for the factor of time. A unique feature of the book is an introduction to special mathematical techniques such as linear programming, and similar optimizing procedures where the number of variables are large. Statistical treatment of cost estimates, particularly to show maximum and minimum profitability, is reviewed briefly.

The second part of the book is concerned with the problems in optimizing the various component parts of a process such as compressors, distillation units, heat exchangers, etc., and with rough rules of thumb for quick estimation of costs in the early

* John Happel: John Wiley & Sons, Inc., New York, 1958. $8.50. 282 pp.

stages of evaluation. Various mathematical techniques are discussed to allow for the time value of money, when costs and incomes vary during the life of the project. There is also a rather elementary discussion of evaluations under free enterprise and planned economy systems.

The level of difficulty of this book is admirably suited to a junior or senior course in engineering economy, and there is a judicious balance of theoretical and practical viewpoints. It should also be of interest to engineers who are concerned with project profitability, and who are interested in an introduction to some of the newer mathematical tools.

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